Art. XII.—*The Mount Morgan Gold Mine, Queensland.*

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(With Plates XXI., XXII.).

[Read 11th August, 1904].

The writer visited this mine in 1889, when the Mount was almost in its original condition, in 1890 and again in 1894, and enjoyed exceptional opportunities of examining the upper and richer portion. The first survey of the mine and surroundings was made under his supervision in 1889. Several comprehensive reports on the mine have been published, of which Dr. Jack's three reports, issued by the Queensland Geological Survey in 1884, 1889 and 1892, are by far the most complete.

In 1887 J. Macdonald Cameron published a report on the mine, and since 1892 the Queensland Geological Survey has issued some short reports about the mine; but so far as the writer is aware no clear description of the structure of the mine, as disclosed to 1894, has been printed.

In 1894 the last remnants of the highly-enriched zone were removed, and the open workings at this time explained much that was previously obscure. The several examinations made by the writer were in the interests of clients, and therefore the data were not available for publication until some time had elapsed.

Dr. Jack's view was that a thermal spring had deposited the auriferous rock at Mt. Morgan. From this view Mr. Cameron dissented. The late Mr. Wesley Hall and the then mine manager (Mr. Lisle) held the view that the oxidization of sulphides accompanied by heat sufficient to melt the quartz even, and an inflow of water from below, caused a "chemical outburst," and the gold and other material was subsequently deposited (Cameron's Report).

Rocks.

From the base to the summit of Mt. Morgan, which attained a height of 580 feet above the Dee River, igneous rocks predominate, and these constitute the country rock within which is enclosed the large mass of siliceous material forming the ore body. South of Mundic Creek is a very extensive tract of course-grained hornblendic igneous rock of uniform character. Higher up the western slope of the Mount, where the Rip and Tear tunnels are, the rock appears to be a decomposed crystalline igneous rock. On the south side of the Mount beds of volcanic ejectamenta, including many fragments of red jasper, are exposed near the New Reduction Works. Further up the spur, and near the mouth of Freehold Tunnel, variolite occurs. On the east side of the Mount from Linda Creek upwards crystalline igneous rocks, such as diorite, syenite, etc., are exposed. On the north side of the Mount a considerable area is occupied by siliceous cavernous rock, from which sulphides have been removed. It is doubtful whether the rocks resembling quartzite met with in the tunnels, etc., are of ordinary sedimentary origin.

The top of the Mount was occupied by, first, a core of soft red sandstone horizontally laid down and much false-bedded, surrounded by beds of loose sand, highly coloured with iron oxides in part, and these again were surrounded by a belt of limonite and beds of sand rich in iron oxides partly stained black from the presence of manganese oxide. Almost entirely surrounding this belt were the siliceous skeleton rocks from which the sulphides had been removed (Tufa of Dr. Jack's reports). Outside this siliceous rock, and forming the walls of the mine, was an altered igneous rock completely kaolinised, but in which the crystals of felspar were still clearly discernible. This rock appears to be an altered diorite. Cutting through the siliceous skeleton rock, and also through the diorite walls of the mine are dykes that also appear to have been originally of diorite, but that are completely kaolinised at the surface.

These dykes do not penetrate the loose sandy beds or the limonite of the secondary ore, nor do they cut through the [1]Desert Sandstone core, for this is of still later age.

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1 Later research renders it improbable that these beds are of Desert Sandstone age.

In the deeper levels of the mine the walls are in an unaltered condition, and appear to be of fine grained diorite. In one case such rock was thickly studded with scales of native copper.

Up to the present no microscopical examination of the extremely interesting group of rocks around Mt. Morgan appears to have been made.

Structure.

As shown on the accompanying plan and section, the top of Mt. Morgan is occupied by a plug three-fifths of an acre in extent of sandstone (A). This sandstone was evidently an outlier from the Desert Sandstone of Dr. Jack, which is so well represented a few chains to the north-west, capping the range. The plug was doubtless at one time continuous with the main mass, and its isolation was due to denuding agencies which have also pared it down to the condition it was in before removal by mining operations. The sandstone was moderately coarse-grained, red in colour at the surface, but nearly white in parts lower down. It was bedded horizontally in beds from a few inches to a couple of feet thick, and extensively false bedded. The mass formed an inverted flattened cone, and filled the inside of the funnel-shaped mass of sandy beds of secondary ore (B on plan and section). Assays of this sandstone gave up to 3dwt. of gold per ton, and this is not remarkable, seeing that the walls of the cavity in which it was laid down were highly auriferous. The whole of this plug, which was nearly 100 feet deep at its thickest part, was quarried and tipped over the side of the Mount, so as to remove the rich secondary ore below it. It was quite distinct from, and unconformable to, the beds of loose sand, etc., underlying it. By means of this outlier of desert sandstone it is clearly established that the secondary ore was laid down before the Desert Sandstone began to be deposited, though probably not long before. From the degraded condition of the plug it is certain that denudation had removed a portion of the secondary ore around the plug, but there was not any means of gauging the extent of this work. Formerly a blacksmith's shop stood on the plug of sandstone.

Surrounding the plug of sandstone were beds of loose sand, etc., very irregularly bedded and disposed somewhat after the form of a rim of a funnel (B on plan). Towards the centre the material was less ferruginous than towards the outside of the area, where highly ferruginous beds and belts of limonite were prominent.

A ferruginous belt (C) extended outside of the beds above described (B), and continued downwards to what would be called the stem of a funnel to a depth of 150 feet from the surface. Much of this ironstone was extremely hard, and Krom rollers were used to crush it. Much of it was extremely rich in gold, which was disseminated through the stone in microscopic particles, but which was occasionally visible to the unaided eye. Assays of hundreds of ounces of gold per ton were obtained from this class of ore.

This secondary ore formed a zone of enrichment, and the whole of the material from the central plug of sandstone to the rim of cellular siliceous rock was payably auriferous. The bulk yielded several ounces of gold per ton, and portions assayed for hundreds of ounces per ton.

Between the ferruginous zone (C) and the leached cellular siliceous ore (E) there was usually a band of sand or soft bed (D) from a few inches to many feet thick; this appeared to be present wherever the floor was moderately inclined, but was absent where the floor of siliceous ore was steeply inclined. This band of loose material was in places extremely rich in gold.

Underlying, and almost surrounding the whole of the above secondary ores, is a great mass of siliceous and kaolin ore (E), representing the upper and oxidised portion of the siliceous sulphide ore met with deeper in the mine. The friable silica is cellular from the removal of the pyrites; a great deal of this in the mine is white, showing how thoroughly it has been leached, but in places the stone was very ferruginous, and in some places a little of the sulphide still remained unaltered. At the surface this stone was generally stained nearly black with manganese oxide. Nodules, with unaltered pyrites, were met with even at the surface. Very large quantities of this ore have been mined for gold at the surface and underground, but a great deal of it is not sufficiently rich in gold to be profitably worked. At the surface there is an extensive area to the north-west of the shaft that is not mined much past the flagstaff, as its gold contents is too low. Kaolin ore occurs extensively developed in this oxidised or impoverished zone. Gold occurs in a most irregular manner distributed through the siliceous and kaolin ore. The average contents of gold in this zone would probably be only dwts. against ounces in the enriched zone.

The oxidisation and leaching of this ore has extended from 180 feet from the surface to perhaps 300 feet in the deepest part, and, as elsewhere, this action has prevailed less deeply along the walls than towards the centre of the mass of ore. There can be little doubt that so fas as leaching has proceeded gold has been conveyed thence in solution and again deposited in the enriched zone, and although the sulphides in their original condition in the upper portion of the mine may have been in no richer gold ore than in the lower portion now being worked, the extensive concentration from an enormous bulk of adjacent ore might account for the wonderful accumulation of gold in the enriched zone or secondary ore.

Formerly the term tufa was applied to the cellular siliceous ore of this zone, and certainly its appearance in the upper workings was unusual, but now that it has been followed down to its roots there is no room for doubting that it is merely the skeleton of silica, the sulphides having been oxidised and leached out.

Everywhere in the mine as depth is attained this oxidised and leached ore is found to give place to sulphide ore, (F) the unaltered zone. The change is gradual in places, and first iron pyrites is met with, then at lower depths copper pyrites is met with associated with the iron pyrites. In the sulphide ores gold is most irregularly distributed, and in the bottom levels the average gold contents has fallen to as low as $1\frac{1}{2}$ dwts. of gold per ton, but the copper contents have increased. In this connection bulk, as against weight, has to be considered, for a ton of sulphide ore would perhaps be only 10 or 11 cubic feet, while a ton of the cellular siliceous ore would probably exceed 30 cubic feet, so that until careful experiments are made as to the proportion of gold per cubic yard in the different portions of the mine it would be unsafe to assume that there is an actual diminution in the gold contents in the original ore as depth is attained.

Then outside the sulphide ore and skeleton ore from which the sulphides have been removed are the walls of crystalline igneous rocks (G), altered at the surface to kaolin, but in the deeper levels unaltered and apparently diorite, etc.; also a similar class of rocks altered to kaolin at the surface, but little altered in depth, which cut through G, F and E as dykes (H). These dykes are clearly of later date than the massive igneous rocks (G), but they are older than, and do not intersect A, B, C, or D. They formed a conspicuous feature on the surface of the mine, ranging from 25 feet in thickness down to mere threads.

Gold-bearing Ores.

Enclosed within boundaries formed of igneous rocks is a great body of quartz of irregular form, and covering many acres at the surface. In depth the quartz is thickly impregnated with sulphides. At the surface, and for a considerable depth below, the sulphides have been decomposed and removed, leaving the siliceous skeleton. This surface rock of siliceous composition and cellular structure was described by Dr. Jack as sinter, but further workings have fully established the fact that the cavernous siliceous rock at the surface is continuous with the upper portion of the quartz and sulphide ore met with in the deeper levels of the mine. Even at the surface odd nodules of ore were met with in the siliceous rock containing unaltered pyyites.

This siliceous sulphide body is undoubtedly the original source from which all the Mt. Morgan gold has been derived.

At the lowest depth attained in the mine, some 850 feet from the summit of the Mount, the ore is a dark-grey, finely-saccharoidal quartz, thickly studded with iron and copper pyrites, the former greatly predominating. This ore carries from $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent. copper and from $1\frac{1}{2}$ dwt. to 8 dwt. of gold per ton. It is noteworthy that some of the iron pyrites is in dodecahedral crystals. In the Pilgrims' Rest Goldfields, S. Africa it was observed that the iron pyrites of pentagonal dodecahedral form was rich in gold, while the cubical crystals were barren.

A prominent feature of this mine is the increase of copper sulphides in depth. Stains of copper were noticeable even at the surface, showing that copper sulphides existed there formerly, and the explanation probably is that the copper sulphides, being more readily oxidised and removed in solution, have disappeared even below where the iron sulphides still survive, but that a zone has now been reached where the ores are in the condition as originally deposited. From an industrial point of view, this change in the character of the ore is serious; for, whereas the ores first worked were for gold only, the future development of the mine must be as a copper and gold proposition, the copper greatly outweighing the gold in importance. Eventually it is likely that the mine may become a copper mine, the gold being merely a by-product. Necessarily following this change in the nature of the ore is an entire alteration in the plant and methods involving heavy expenditure.

Origin.

As to the origin of this great body of siliceous and sulphide ore, there is some obscurity. Its great mass and its relations to the surrounding igneous rocks differentiate it from ordinary lodes. Besides, at the Sugar Loaf another similar body of ore exists also with similar surroundings, and still others in the neighbourhood. Whether it resulted from igneous agency or not has yet to be worked out, but the intimate manner in which similar cavernous siliceous material was blended with the felspathic material at the archway that formerly stood at No. 3 level as observed by the writer seemed to point this way.

Dykes of various dimensions cut through the siliceous sulphides in many places, and the rock is not as altered as at higher levels.

In the upper levels, besides the friable siliceous material, very extensive bodies of kaolin ore were also met with and extensively mined. Although the kaolin ore in some cases was undoubtedly produced from the decomposition of dykes of felspathic rock that were not necessarily auriferous originally, but that may have become so through the decomposition of the auriferous sulphides in the siliceous ore around them, and the gold derived from the pyrites in solution may have been redeposited in the kaolin, it is not certain that all the kaolin could be thus accounted for. In some parts the ore itself appears to carry much kaolin, but this point will be far clearer in the lower levels now being opened out.

In No. 5 tunnel, east end, dyke material now kaolinised ramifies through the siliceous ore as under:—

Of still greater interest than the sulphide ore and the skeleton ore, from which the sulphides have been removed, is the secondary ore. It is of most unusual character, and the writer has not met with anything similar elsewhere. The distinction between this ore and the cellular, siliceous ore surrounding it appears not to have been sufficiently emphasised, and this has probably led to some confusion. In the earlier stages of the mine the relation of this ore to its surroundings was obscure, but the further operations that resulted in the removal of the whole of it, and also of the plug of sandstone in its centre by open cast workings, disclosed these relations in a very distinct manner.

Roughly, the secondary ore of Mt. Morgan was funnel-shaped. It was surrounded at the surface by the cellular siliceous ore on the north and west sides, and by kaolinised igneous rock on the south and east sides. In outline it was of irregular oval form and covered, with the plug of sandstone in its centre, an area of about 2½ acres on the top of the Mount. The extreme summit of the Mount was just west of the edge of this area. Everywhere this ore covered the cellular siliceous ore, and to a depth of 50 or 60 feet, but extended to a depth of 160 feet from the surface in the deepest part. Within this area the material consisted of fine and coarse siliceous sand, some of the beds so incoherent that the sand ran freely; other beds were more clayey. The beds were highly inclined, very irregular in extent and varied much in thickness within short distances; but were less inclined, though still very irregular in the north-west portion of the area.

Some of these beds of sand were of light grey colour, but most were stained with oxide of iron, and towards the outer edge the beds were of brilliant reds, yellows, purple, and nearly black in some cases from a high percentage of iron and manganese oxides. In section, some of these beds were fan-shaped, as observed by Dr. Jack. A highly-ferruginous belt formed the outer margin of the area, represented in places by bands of limonite that attained a thickness of twenty feet in places. The greatest development of limonite was just north of the shaft. In the south-east portion of the area limonite was also strongly represented. The limonite was of light brown colour, very hard, and contained grains of quartz scattered through the mass. Before the surface was cut up by mining the area occupied by secondary ore was plainly defined by a distinct, and in places very strong, outcrop of ferruginous material. Limonite formed a conspicuous feature at the surface, projecting 10 or 12 feet above the ground in places. It did not occur in a solid vein, but in irregular more or less spherical blocks with botryoidal or stalactitic surface, and up to a ton in weight. Some of the limonite was light and frothy, stained black from manganese oxide, or most brilliantly iridescent. Generally there was a selvage of sandy material resting directly on the cellular siliceous ore, then the limonite. This selvage ranged from a few inches to many feet in thickness. In places this sand was spangled with fine particles of scaly gold. Where the portion corresponding to the stem of the funnel was it consisted of blocks of limonite bedded in red clay. It was the marvellous richness of this secondary ore that established the fame of Mt. Morgan, and that supplied many millions' worth of gold within a few years. Morgan's first trench was in this class of ore. Immense quantities of ore from this portion of the mine gave 8 to 10 ozs. of gold per ton. Some of the sandy beds yielded up to hundreds of ounces per ton. The richest spot was about 20 feet north-west from the shaft on No. 3 floor. The limonite also in places was phenomenally rich in gold; some large blocks assayed up to 800 ozs. per ton. Taken as a whole, the secondary ore was a marvellously rich deposit of gold-bearing material. It represented a zone of enrichment, and the gold it contained was derived by the leaching and impoverishment of an enormous mass of adjacent ore.

When the great richness of the surface ore at the Mount was proved, prospecting was eagerly pushed on with the object of discovering the continuation in depth, but although the Mount was pierced right through at several points and right beneath where the rich ore stood, no continuation could be discovered below, and the reason is obvious from the plan and section given. For while the workings at the surface were in the enriched zone of secondary ore the tunnels were driven through the impoverished zone of cellular siliceous rock from which the sulphides and much of the gold had been leached out.

The secondary ore was, with the exception of the ironstone, in such a loose and friable condition that most of it was removed with a shovel.

It is quite possible that in the secondary ore a certain amount of Desert Sandstone material may have been mingled with the material resulting from the disintegration of the cellular siliceous rock, for the Desert Sandstone sea must have covered this area while the secondary ore was being formed, and that some sand should have been carried in seems quite natural.

Gold.

In the enriched zone gold existed not only in exceptional abundance, but the quality was abnormally high; in fact, no naturally-formed gold is known that more nearly reached chemical purity than the gold obtained near the surface at Mt. Morgan. Thousands of ounces were bought at the Sydney Mint that were 99.7 fine, and some reached 99.8. This unusual degree of fineness was certainly due to the processes by which the much-alloyed gold of the sulphides was first dissolved and leached out of its original ore and then re-deposited under such conditions that no silver was deposited at the same time.

Such pure gold was confined to the secondary ores of the enriched zone. The siliceous and kaolin ores of the impoverished zone carried a considerable percentage of silver alloy, amounting to 43 per cent. in some cases, and as the gold in the secondary ores was furnished from the ore that yields bullion with much silver, it is evident that the silver has been got rid of in its transference from the leached ore to the enriched zone.

Lower still in the mine the gold of the sulphide zone is much alloyed with silver.

A characteristic of the gold at Mt. Morgan was its extreme state of subdivision. This was so much the case that some examples carrying scores of ounces of gold to the ton showed nothing that could be detected by the naked eye, even in some cases ore carrying over 50 ozs. per ton disclosed no visible gold. In the trench sunk by Morgan where the stone was fabulously rich the gold was excessively minute. It was visible in the ironstone in places as small crystalline flakes and also as loose crystalline spangles thickly disseminated in some of the beds of loose sand. Before Mt. Morgan was discovered alluvial gold was worked in Linda Creek.

The extremely fine character of the gold at first proved an impediment to its extraction, as it could not be recovered by the ordinary battery and amalgamation. Assays of the tailings showed that but a fraction was being recovered. Chlorination was had recourse to, and solved the problem.

As much as £4 4s. 8d. per oz. was paid for the earlier parcels of gold from this mine.

Throughout the mine in the several classes of ore the distribution of the gold was most erratic, one assay would give but a trace ; the next might give ounces per ton.

Of such great fineness were the particles of gold that the red dust which escaped from the dust chamber of the mill taken at a distance of a mile away, yielded assays of 1 oz. per ton, as the late Mr. Wesley Hall informed the writer.

In 1889 over a ton of gold per month was being despatched from the mine, and this continued for about a year.

It is curious that although the gold of this mine occurs associated with much copper in the form of sulphide, it does not appear to be alloyed with that metal, but with silver. The total yield of gold to June, 1904, is about $111\frac{1}{2}$ tons; worth £11,150,087. Average value of the gold about £4 1s. $0\frac{3}{4}$d. per oz.

Geological History.

In considering the series of events that have combined to produce Mt. Morgan as it stood when mining operations began, the period preceding that at which the Desert Sandstone sea covered the Mount, will not be considered, as these antecedent events can be more accurately and easily followed when the lower workings are further developed.

At the time this sea encroached on the top of the Mount, there was a large area of siliceous ore bounded by igneous rocks, exposed at the surface, that had undergone some denudation, as proved by the position of the "overflow" of Dr. Jack, and this ore had no doubt become oxidized to a greater or less extent. Still, it is not probable that oxidization had penetrated to a very great depth. When the water from the sea spread over this ore with unaltered sulphides near the surface a violent set of reactions appears to have been set up in the area now occupied by the secondary ores.

Why this special area should have been the centre of so much activity is not apparent, unless it represents a portion of the ore mass more highly charged with sulphides than the rest, or with sulphides more easily oxidizable than in the surrounding mass. The effect of this action was to completely disintegrate the siliceous sulphide mass of ore, and to oxidise the sulphides and dissolve the gold and silver contained in the sulphides. Only a violent mechanical action, the result of fierce chemical reactions, could have torn this ore apart and reduced it to the condition of sand and argillaceus material, such as formed the secondary ore. The extremely irregular manner of the deposition also points out that the water it was laid down in was not by any means quiescent. All the materials found in the secondary ore beds are such as would be furnished by the siliceous sulphide ores; but the whole of the material supplied by the sulphide ore was not laid down again in the area in which the violent reactions took place. A great deal of it, in suspension as fine mud, was carried further away, and may now be seen at a lower level on the sides of the Mount, covering the rocks and surface as exposed before the Desert Sandstone was laid down. This bulk of "overflow" should, roughly, represent the space left in the secondary ore, and subsequently filled in by a plug of Desert Sandstone, plus, perhaps, some of the material subsequently leached out from the sulphides at lower levels.

The sand of the secondary ore came from the siliceous component of the ore, the aluminous material from the kaolinised dykes, etc.. and perhaps from portions of the ore either in the form of solution or suspensin, or both ; the limonite was supplied by the decomposition of iron pyrites. As solvents of gold, supposing the waters were sea waters, there would be chlorine, bromine, iodine, etc.

When the more violent conditions ceased, the materials filling a basin shaped cavity began to re-arrange themselves, and first the heavy iron solutions and the coarse sandy particles were laid down, and with these much of the gold in solution was deposited, but not the silver ; and this would imply that conditions prevailed favouring the deposition of gold, but not silver, from the solutions. In this way the gold was so completely parted that it approached chemical purity.

Although an area above described was subject to powerful action, by which the ore was completely disintegrated, the rest of the area of sulphide ore exposed to the same action was not disintegrated, but the sulphides were merely oxidised and leached away, leaving the siliceous skeleton standing at the surface ; this was usually nearly black from manganese oxide.

Just as the disintegrated portion of the ore only extended on the surface over a certain area, so downwards the disintegration was also limited. The deepest point was about 150 feet from the surface, but over much of the area the depth was much less than this. So that beyond the limits of the disintegrating forces the chemical reactions appear to have been less active ; perhaps they were slower, and possibly the sulphides were less plentiful or of a different composition.

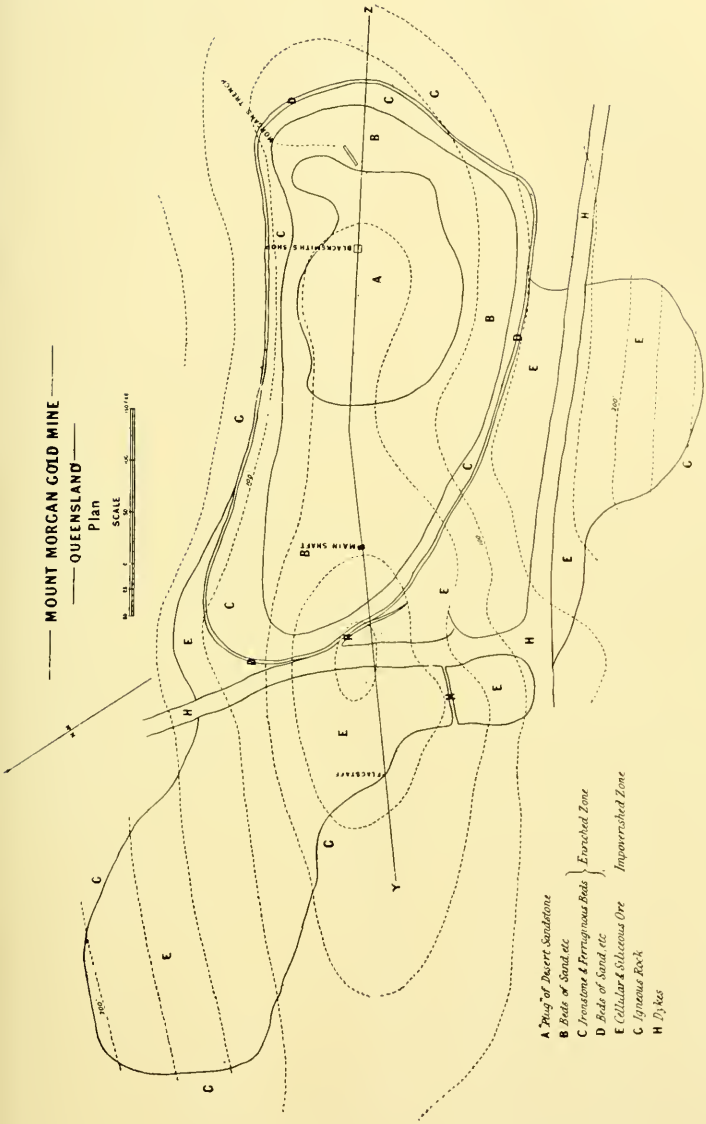
Still, oxidization and leaching of the sulphides continued long after the disintegrating forces ceased to act, and may have continued down even to the present time.

The action of sea water on the sulphide ore is held by the writer to sufficiently account for the phenomena of the secondary ores of Mt. Morgan without calling in the aid of thermal springs. Besides the thermal spring was meant by Dr. Jack to account for the origin of the siliceous skeleton of the sulphide ore which he then called sinter; but this skeleton has now been traced downwards, and proved to be the upper leached portion of siliceous sulphides.

It would not be necessary to invoke the aid of a thermal spring if sea water could accomplish the work, for it is certain that this spot was covered by the sea or a lake about the time when the violent disintegration was at work, for as soon as the sands and clays had re-settled in the basin, leaving a cavity in the centre where the activity lasted longest, then horizontal beds of Desert Sandstone were deposited, and these were piled up to a height of 100 feet or more within the centre of the basin, the ends of the beds resting on the sands, etc., of the secondary ores, and this accumulation went on until such horizontal but much false bedded sandstones were built up for perhaps hundreds of feet above the top of the Mount as presented when mining began. These accumulations of sediment went on until the conditions changed, and the sediments emerged from the sea and were exposed to the air. Since then extensive denudation has been at work, removing the cover of sandstone from a great area about Mt. Morgan, leaving the plug on the Mount itself because it was protected from wear and tear by being countersunk in the secondary ore. These denuding forces are still in full activity, carving the valleys deeper and lowering the summits and ridges.

It is probable that the actual disintegration and subsequent re-deposit of the secondary ore did not occupy any very long period; the very fierceness of the action would imply a rapid completion, and no doubt most of the gold from the ore disintegrated was thrown down again within the basin, but this would not account for all that was found there.

Some small proportion of the gold was certainly carried away in the slimes or "overflow," and assays of this "overflow" material were said to yield small assays of gold. But if a little thus escaped, it is probable that the secondary ores were


MOUNT MORGAN GOLD MINE
QUEENSLAND
Plan
SCALE
MORGANS TRENCH
BLACKSMITH'S SHOP
MAIN SHAFT
FLAGSTAFF
Z
Y
A "Plug" of Desert Sandstone
B Beds of Sand, etc
C Ironstone & Ferruginous Beds
D Beds of Sand, etc
Enriched Zone
E Cellular & Siliceous Ore
Impoverished Zone
C Igneous Rock
H Dykes